Wearable Electric Potential Sensing: A new modality sensing hair touch and restless leg movement

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Abstract

Electric potential sensors (EPS) are classified as capacitive sensors with the ability to measure small variations in electric potential or electric field remotely and accurately. Here we show how a low cost single chip version of EPS can be integrated into a wearable device such as smart watch to provide relevant information about habitual movements specifically, hair touching and scratching as well as leg movement. This new modality could be used in consumer care product research such as studying the quality of shampoos and to study restless leg syndrome remotely without the need of wearing additional sensors. In both scenarios, a single sensor was worn on the wrist, similar to a smart watch, with the sensing electrode pointing away from the body (i.e. no skin contact).

Author Keywords

Wearable sensors; Hair brushing detection; remote leg movement detection; Electric potential sensor (EPS)

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous. H.5.2 User Interfaces: Input devices and strategies (e.g., mouse, touchscreen). I.2.9 Robotics: sensors. J.2 Physical science and engineering: Electronics.

Introduction

We have explored the applications of a sensor modality that has recently become commercially available, an electric potential sensor (EPS) from Plessey Semiconductors. The PS25255 is an EPS available in the form of a monolithic low cost integrated circuit [5]. It is designed with the intention to measure electrophysiological signals such as ECG and EMG with a flat frequency response from 0.2 Hz to 20 kHz. The sensor has 20 GΩ of input resistance and input capacitance of 15 pF. This allows remote measurement of small variations in voltage signals and the ambient electric field non-invasively. Capacitive sensors have been used in the environment for human-computer interaction [2, 4] with limited work on body-worn sensors [3] except for [8] where the authors carried out a similar experiment using another type of body worn capacitive sensor to detect walking and jogging. However, their design topology suffers from saturation due to static charge build up while EPS is DC-stable, which means it recovers from saturation without the need of switching circuitry. It has previously been shown that EPS can also measure the amount of static charge build-up [10].

Here we found that EPS can be integrated into a wearable device to provide information about specific events such as running hands through the hair and head scratching, shaking a leg or legs and lifting them off the ground. The first could have potential applications for consumer behavioral research in the consumer care product sector and the latter could be used to detect restless leg syndrome from a single EPS sensor mounted on a wristwatch without the need for wearing additional sensors on the legs.

Sensing electric field on the body requires a wireless wearable data-logging platform. Wired data acquisition solutions significantly affect coupling to the surroundings and thus distort the measurements. We have designed an extensible wearable research platform that addresses these requirements. It comprises of an AVR8 microcontroller running at 11 MHz, 3 V voltage regulator, battery charger, micro-SD storage, motion sensor (3D accelerometer, 3D gyroscope), USB and Bluetooth interface. It also has a real-time clock with 5ppm accuracy over the entire temperature range (-40°C to +85°C). The platform accepts extension boards on top or bottom. Figure 1 shows the data-logging platform and the EPS sensor extension board.

On the sensor extension board, the analog output of the EPS chip is amplified by a factor of 20, band-limited from 16 to 60 Hz and level shifted by a single op-amp stage before it is fed to the ADC. The circuit schematic for the sensor extension board is shown in Figure 2. On the data-logging platform, the signal is sampled at 1 kHz using the 10-bit ADC available on the microcontroller. The digitized data is then transmitted to a Bluetooth enabled computer for recording and analysis. The data is low-pass filtered at 35 Hz using a 20th order Butterworth FIR (finite impulse respond) digital filter to remove the effect of 50/60 Hz ambient electric field. Figure 2 present a functional block diagram of the data-logging platform.

Two independent experiments were carried out to detect running a hand through hair and leg movement. In both cases, the sensor was worn on the left wrist similar to a watch, with the sensing electrode facing away from the body (i.e. no skin contact). Furthermore, the ground of the sensor circuit was floating and all analogue and digital signal conditioning parameters were identical for both measurements.

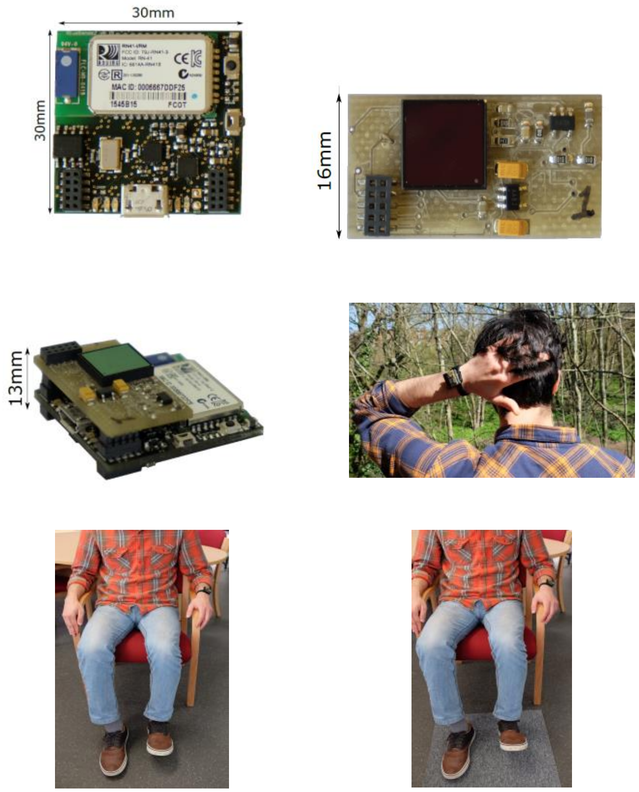

Figure 1. Top left, shows the wearable data-logging platform. Top right, the sensor extension board. Middle left, shows the data acquisition/logging platform and the sensor board assembled. Middle right, shows the hair touching experiment setup, the sensor is worn on the wrist with the sensing electrode pointing away from the body. Bottom shows the setup for leg movement experiment with two kinds of flooring.

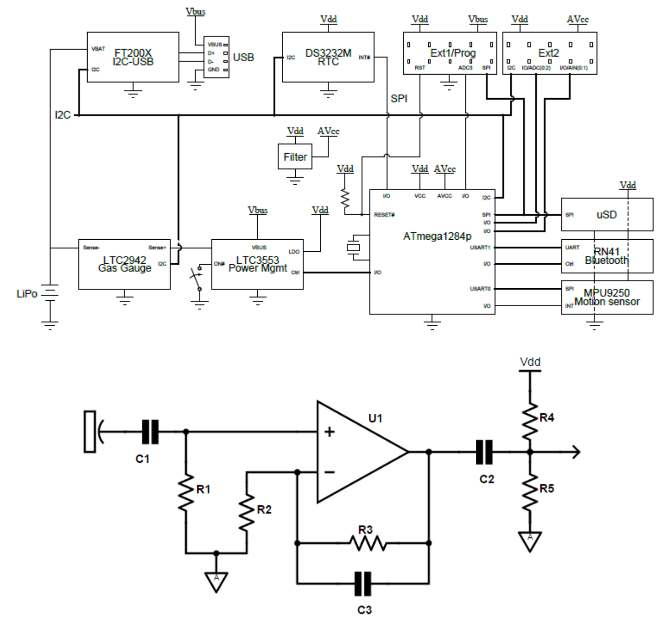

Figure 2. Top shows block diagram of the custom–built wearable data-logging platform based around and AVR8 processor and a Bluetooth 2.0 module. Bottom, schematic diagram of the sensor extension board. The input to the op-amp comes from the analogue output of the Plessey EPS sensor IC and the output of the op-amp circuit is fed to the ADC of the AVR chip.

Hair Touch Detection

Figure 3 shows the sensor output when running a hand through the hair and when scratching the head. The sensor measures the transient response due to triboelectric charging effect (Figure 3). This could lead to hair touch detection by computing the standard deviation in a sliding window and comparing it to a threshold. This is a similar mechanism to statically charging a balloon by rubbing it on hair. We know that the static charge build-up rate of human hair has also been linked to greasiness level of the hair [5]. Interestingly, we can also detect hair touch from the non-instrumented hand (Fig 3 B1 & B2) however; the signal is smaller in this case. Figure 3, C1 and C2 show the output of sensor when scratching the head. Notice the gradual increase in amplitude when scratching the head with the instrumented hand in Figure 3, C1 and C2. In this circuit configuration the maximum input signal seen by the sensor before saturation is ±7 mV. An example of how quickly the sensor output recovers from saturation is shown in Figure 3 C2.

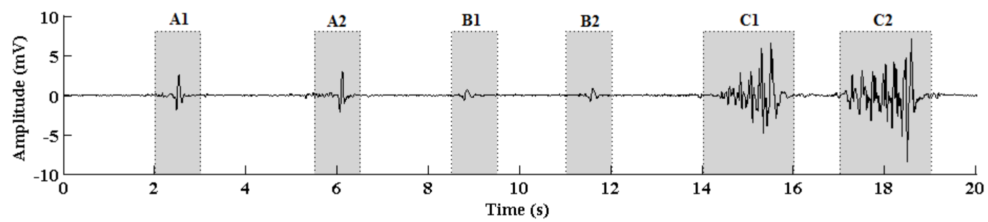

Figure 3: Electric potential sensor response due to triboelectric charging effect caused by running hand through hair while wearing the sensor on the left wrist. A1 and A2 show two instances of the transient response caused by running the left hand through hair. B1 and B2 show the sensor response when using the right hand. C1 and C2 show the sensors output caused by scratching the head, note the gradual increase in amplitude in the case of scratching. All voltages are referred to input.

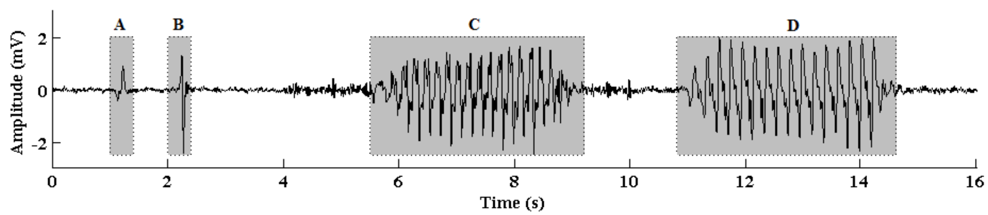

Figure 4: Wrist-worn electric potential sensor response to leg movements while seated. A shows the effect of lifting the foot off the ground and B shows the effect of returning the foot to the ground. Note the opposite polarity in each case. C shows the effect of shaking the right leg on carpet flooring and D, the effect of shaking the left leg on vinyl flooring. Amplitude is referred to input.

Remote leg movement Detection

Figure 4 shows the result of the leg movement experiment. Here, the instrumented hand was resting on the arm of the chair while seated (Fig 1). The experiment was carried out on two different floorings, carpet and vinyl. Figure 4 A and 4 B are the signals from instances of lifting a foot off the ground and returning it on the vinyl flooring respectively. The leading edge is negative in case of lifting and positive in case of returning, this could be used to distinguish both events independently. Figure 4 C shows the sensor response to left leg shaking on carpet flooring and Fig 4 D shows the result of shaking the right leg on a vinyl floor. The resulting signal is related to the frequency of leg shaking. In this case the ambient electric field seen by the sensor is modulated due to change in capacitive coupling between the body and the ground. The foot can be resting on the floor while shaking and does not have to leave the ground completely.

Conclusion

We have integrated an EPS into a wrist worn device similar to a smart watch. This enabled us to detect running a hand through hair and measure various leg movements remotely. This has potential applications in consumer care sector [9] and to study restless leg syndrome. We envision that EPS could be used within the sensor fusion framework along with other modalities such as an accelerometer [1] to disambiguate activity recognition and therefore increase recognition accuracy [7]. We have shown that using EPS limits the need for wearing additional sensors modalities anywhere other than the wrist to detect leg movements and hair touch. Electrostatic charge build-up is usually an unwanted effect when measuring the ambient electric field [8]. Not only EPS is less susceptible to saturation from triboelectric charging, it is capable of measuring electrostatic charge build-up; owing this to its inherent DC stability. The small form factor (1x1x0.2 cm) of the EPS and its integrated sensing electrode along with its multi-functionality and low power consumption make EPS a good candidate for wearable applications. In future, we plan to enhance the activity recognition by combining elements such as signal amplitude and movement data from an accelerometer.

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References

1. Bao, L., and Intille, S. S. Activity recognition from user-annotated acceleration data. In Pervasive Computing: Proc. of the 2nd Int'l Conference (2004)

2. Braun, A., Frank, S., et al, - capacitive proximity sensing for automotive activity recognition. In Proc AutomotiveUI (2015)

3. Cheng, J., Amft, O., and Lukowicz, P. Active capacitive sensing: Exploring a new wearable sensing modality for activity recognition. In Proc of Pervasive Computing (2010).

4. Fu, B., Grosse-Puppendahl, T., and Kuijper, A. A gesture recognition method for proximity-sensing surfaces in smart environments. In Distributed, Ambient, and Pervasive Interactions (2015)

5. Lunn, A.,Evans, R. The electrostatic properties of human hair. J. Soc. Cosmet. Chem (1977)

6. Plessey Semiconductors. PS25255 EPIC Ultra High Impedance ECG Sensor. Issue 1.

7. Stikic, M., Huynh, T., Van Laerhoven, K., Schiele, B. ADL recognition based on the combination of RFID and accelerometer sensing, Int Conf on Pervasive Computing Technologies for Healthcare (2008).

8. Gabe Cohn, Sidhant Gupta, Joshua R. Smith, N. Patel. An Ultra-Low-Power Human Body Motion Sensor Using Static Electric Field Sensing. UbiComp (2012).

9. Yuan, Haibo, Xiaozhong Shen, and Qian LI. "BRUSH SENSOR FOR MEASURING STATIC CHARGE OF FIBERS." U.S. Patent No. 20,160,011,233. 14 Jan. 2016.

10. Beardsmore-Rust, S., Watson P., Prance, R. Imaging of charge spatial density on insulating materials. Measurement Science and Technology, (2009).